(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 July 2003 (31.07.2003)

PCT

(10) International Publication Number
WO 03/062597 A1

(51) International Patent Classification⁷: E21B 43/38, B01D 17/02

(21) International Application Number: PCT/NO03/00018

(22) International Filing Date: 21 January 2003 (21.01.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
20020344 22 January 2002 (22.01.2002) NO

(71) Applicant *(for all designated States except US)*: **KVÆRNER OILFIELD PRODUCTS AS** [NO/NO]; P.O. Box 94, N-1325 Lysaker (NO).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **HOMSTVEDT, Gunder** [NO/NO]; Hauketoåsen 17, N-1277 Oslo (NO). **ASHEIM, Harald** [NO/NO]; Trymsvei 8, N-7033 Trondheim (NO). **ROLL, Albert** [NO/NO]; Lilleborggate 7, N-0480 Oslo (NO).

(74) Agent: **PROTECTOR INTELLECTUAL PROPERTY CONSULTANTS AS**; P.O. Box 5074 Majorstuen, N-0301 Oslo (NO).

(81) Designated States *(national)*: AE, AG, AL, AM, AT (utility model), AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ (utility model), CZ, DE (utility model), DE, DK (utility model), DK, DM, DZ, EC, EE (utility model), EE, ES, FI (utility model), FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK (utility model), SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

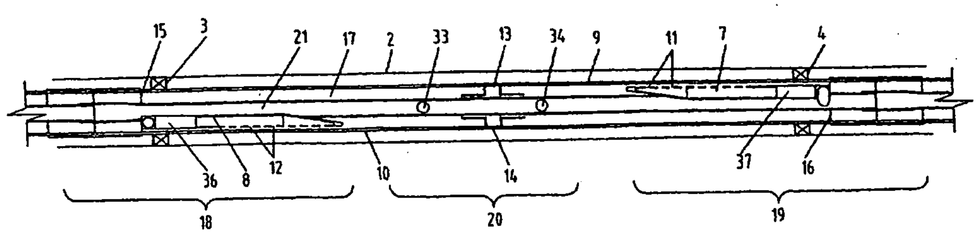
(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)*

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: DEVICE AND METHOD FOR COUNTER-CURRENT SEPARATION OF WELL FLUIDS



(57) Abstract: A separator-cell construction and a connection of several such separator-cells in parallel; a device and a method for separating well fluids from different zones independent from each other in an inclined part of the well and/or a horizontal part of the well; a separator with at least two inlet openings (13, 14) for the well flow, one (13) situatedat a higher altitude than the other (14), to utilize the pre-separation of the well fluid before it enters the separation chamber and provide that the hydrocarbon enriched part of the well fluid enters the higher opening and the water enriched part of the well fluid enters the lower opening are described.

WO 03/062597 A1

DEVICE AND METHOD FOR COUNTER-CURRENT SEPARATION OF WELL FLUIDS

The present invention relates to methods and devices for separation of well fluids according to the preamble of at least one of the enclosed independent claims.

In particular the invention relates to devices and methods for downhole counter-current separation of well fluids.

During production of hydrocarbons from subterranean wells, water will be produced in addition to the hydrocarbons. The water is usually of a higher density than the hydrocarbons and thus tending to collect in the lower cross section of the wellbore and a stratified flow pattern will be formed. Water will also flow at a lower velocity than the hydrocarbons in inclined wells due to gravity forces. It can even flow downwards in some sections of the well.

Most wells will late in their production life cycle experience increased water production. Old fields are therefore typically producing more water than hydrocarbons. Hence one of the most challenging tasks for the industry is to handle these huge quantities of produced water.

A particularly challenging aspect of this issue is the fact that most of these old wells cannot carry the cost of re-drilling or a full work-over. Cheap retrofits would therefore be the ideal solution. Most of these wells have no horizontal section with the consequence that downhole gravity based *horizontal* separation cannot be implemented. A separation system that can be applied in a deviated well would therefore be of great interest.

There are two important previously known methods for downhole separation;

- The cyclone based system, which has been known for quite a while, has so far been a limited commercial success due to questionable reliability, and

- The gravity based separator systems, where low rate systems, Dual Action Pumping System (DAPS) handling less than 200 m3/d, have been tried with mixed results, while high rate systems not have been commercially applied yet.

Two types of high rate gravity based separator systems are known; the horizontal separator by Norsk Hydro described in WO 98/41304 and the inclined well separator by Schlumberger described in GB 2 326 895, as well a variant of this by ABB described in Norwegian Patent Application 2000 0900.

The basic concept behind the downhole horizontal separation system described in WO 98/41304 is to control the flow-rate of the formation fluid in a horizontal section of the well to such a rate that stratification occurs. The separated oil is allowed to flow freely to surface assuming sufficient bottom hole pressure (gas lift or other artificial lift methods might be used otherwise). A downhole pump is used to inject the separated water into a suitable zone.

The downhole gravity based separation systems of GB 2 326 895 and NO 2000 0900 are suitable for inclined well bores. The system of GB 2 326 895 is similar to the WO 98/41304 except in that it suggests two outlet tubes, one taking the oil and the other the separated water. A sensor located close the outlet openings will be used to control the rate of outflow. Compared to WO 98/41304 this system claims to be working at inclinations from 0 to 50 degrees. The system of NO 2000 0900 also claims to work in inclined wells where the heavy fluid component (water) is allowed to be separated out of the incoming fluid through openings in a tube into a second channel formed between the outside this tube and the casing of the well.

Such systems will require a stratified flow patterns inside the separation chamber in order to work. Oil, being lighter than water, will flow upwards in the uppermost layer reaching the oil outlet. Water will flow at a lower velocity or flow in a counter-current direction inside the separation chamber (depending on the angle and overall flow rate) and be picked up by the water outlet tube or the drain-openings. The maximum

allowable slip velocity between oil and water is a critical parameter in determining the overall capacity of such a system. When this slip velocity increases above a certain maximum value, the fluids will re-mix at the interface and separation will break down.

The advantage is however the ability to work within an inclined bore-hole.

Studies have been undertaken by the applicant during spring/summer 2001 with the objective to establish a new downhole separation device that could be suitable, e.g., as a retrofit to old, wet wells.

The following criteria were established as basis for a possible downhole separation system to be retrofitted to such old, wet wells:

1. No re-drilling required
2. Fit inside standard casings sizes: 7" and 9 5/8"
3. Work in inclined wells
4. Avoid rotating equipment (pump, compressor) in the well if possible
5. Separated phases (hydrocarbons and water) channelled to surface, alternatively water channelled to a low pressurised underground formation without using a pump
6. A minimum of downhole monitoring and control (for simplicity)
7. Separated phases being clean enough to by-pass 1. and 2. stage separators at the surface
8. Work at all water-cuts
9. Accept high flow rate (typically above 2000 m^3/day)

There is currently no downhole separation technology that fit these criteria.
Cyclone based downhole separation technology will not meet criteria No. 7 and 8.
Low rate gravity based systems will not meet criteria No. 5 and 9.
Downhole Horizontal Separation (high rate) will not meet criteria No. 3.
Ongoing developments of rotary separators will not meet criteria No. 4.
The gravity based systems for inclined holes will not meet criteria No.9. (see below).

Consequently there is a need to fill these technology gaps since the market feedback indicate that there is a large need for this kind of installations.

On this basis it was decided to make a technical evaluation of the Counter-current Separation (CS) principle (similar to what is described in GB 2 326 895 and NO 2000 0900) which is depending on an inclined bore hole to function. The system is based on separation by gravity, but with the difference from WO 98/41304 that water is led in the opposite direction to the oil. Gravity will make water collect at the bottom of the well where an outlet tube or a pump is located to dispose it to surface or into an injection zone. Compared to WO 98/41304, a substantial slip velocity will be present between the oil and the water phases. Tests have shown that this will become a limiting factor for the overall capacity of such a system.

The tests showed that to be effective the flow velocity in the well bore would have to be reduced to about 10 – 20 % of the outlet flow rate of a normal high rate well. Consequently, the separators of GB 2 326 895 and NO 2000 0900 will only be useful for lower rate wells.

To overcome this limitation the present invention in one aspect prescribes the concept of a CS-cell construction and in another aspect connection of several of such CS cells in parallel.

In yet another aspect the invention prescribes a device and a method for separating well fluids from different zones independent from each other. The separation can take place in an inclined part of the well and/or a horizontal part of the well.

In yet another aspect of the present invention it prescribes at least two inlet openings for the well flow, one situated at a higher altitude than the other, to utilize the pre-separation of the well fluids that naturally takes place in the well before it enters the separation chamber, and provide that the hydrocarbon enriched part of the well fluid

enters the higher opening and the water enriched part of the well fluid enters the lower opening.

The invention as defined in the appended claims will result in one or more of the following advantages:

- Increased total flow capacity
- The various cells can be tuned to handle various water-cuts (WC) as the upper cells are likely to handle lower WC than the lower units
- Increased overall efficiency since the upper cells will receive more clean oil and less water while lower cells have more clean water and less oil to remove
- Can be combined with inflow zone control to improve reservoir drainage
- Each cell can be adjusted for various inflow pressure along the well bore

One particular interesting advantage of such a system is to utilise the control valves in each separation cell for inflow zone control. This will require that each section of the well, that is to be drained separately, will have to be isolated from the others by packers. The main advance with such a system is to obtain a combination of both balanced and optimised reservoir drainage and improved separator performance.

To get an indication of the possibilities with CS cells, a simple test was initiated.

A 7,9 meter long tube of 100 mm diameter was made with an inlet arrangement in the mid-section. Oil and water header tubes were included in the main tube. The tube could be tilted to various angles. A mixture of oil and water was entered in the mid-section. Separation and counter-current flow would take place as described above. The oil/water system consisted of Exxol D80 (a de-aromatized paraffin) and fresh water.

The following parameters were varied during the test:

- Separation tests were conducted at angles between 4 and 47 degrees
- Flow rates were increased until no separation would occur due to creation of emulsion by the break-up of the oil/water interface

- Water-cut was varied from 27 to 79 %

The following observations were made:

- High flow rates created more emulsions
- Separation efficiency was lowest at the inversion point (approx. 50% WC)
- A jump in the interface level was detected at superficial velocities between 0,015 and 0,02 m/s
- Adding emulsion breaker increased the max. flow rate that could be achieved before separation-breakdown took place

The test showed that:

- A higher separation capacity could be achieved for oil-continuous flow (low WC) compared to water continuous flow (high WC).
- The total separation capacity seemed quite constant for WC above the inversion point (in the low WC region)
- The separation capacity increased with increasing inclination up to approx. 36 degrees
- Control of the oil/water interface was more difficult at high angles
- The separation capacity was enhanced by use of emulsion breaker (approx. double rate at 7 degrees)
- A maximum total flow rate (oil + water) was estimated for a 9 5/8" casing separator (ID 222 mm) based on the separation test.

The following conclusions can be drawn from these tests:

- Separation can be achieved at a wide variation of angles, but angles above 5-10 degrees and below 35 –40 degrees seems to be the most favourable for counter-current separation
- The separation efficiency seems to be 50% lower above the inversion point (in the high WC region) compared to below
- The total separation capacity is too low for a stand-alone unit used in a high rate well
- Active level control is necessary for achieving good product quality

- The effect of improved separation under downhole conditions can be illustrated by the 100% increase in efficiency at 7 degrees by using emulsion breaker.

The present invention also provides for utilising the pre-separation that has occurred outside of the separator chamber prior to entering the separator, preventing re-mixing of the separated counter-current oil/water flow with the incoming fluid flow, and thus minimising flow disturbance and increasing efficiency.

Although the present invention is mainly aimed at separators and methods for separations in an inclined well, at least some embodiments of the invention are also useful for horizontal wells.

The invention will be described in detail below in an embodiment of the invention, under reference to the accompanying drawings, in which:

Figure 1 shows a section of a well bore with a separator according to the invention,

Figures 2a – 2d show the lower section of the separator in figure 1,

Figure 2a shows the lower section in the same cross section as in figure 1,
Figure 2b shows a cross section along G – G in figure 2a,
Figure 2c shows the lower section of the separator in a longitudinal section transverse to the longitudinal section of figure 2a, along B – B in figure 2d,
Figure 2d shows a cross section along C – C in figure 2a,

Figures 3a – 3d show the upper section of the separator in figure 1,

Figure 3a shows the upper section in the same cross section as in figure 1,
Figure 3b shows a cross section along F – F in figure 3a,
Figure 3c shows the upper section of the separator in a longitudinal section transverse to the longitudinal section of figure 3a, along B – B in figure 3d,
Figure 3d shows a cross section along H – H in figure 2a,

Figures 4a – 4d shows the middle section of the separator in figure 1,

Figure 4a shows the middle section in the same view as in figure 1,
Figure 4b shows a cross section along D – D in figure 4a,
Figure 4c shows a longitudinally section along B – B in figure 4d,
Figure 4d shows a cross section along E – E in figure 4a,

Figure 5a shows a detailed view of the left end of figure 2c and Figure 5b shows a cross section along C – C in figure 5b.

The term hydrocarbons are used below as the term for the desired fluid from the formation. This comprises at least oil, but may also comprise a minor amount of gas or condensate.

In figure 1 is schematically shown an embodiment of a separator cell according to the present invention, for counter-current separation in an inclined well bore. The well is drilled through a hydrocarbon containing layer (production zone 1). As shown in figure 1, and as is the case in many situations, a casing 2 is delimiting the well from the production zone 1. Perforations are made through the casing wall (not show) to enable flow of reservoir fluids into the well. Above and below the production zone 1, packers 3 and 4 are placed. The packers 3, 4 isolate the part of the well that passes through the production zone 1 and can be located at other places than shown at figure 1. Several perforation slots are typically made along the casing 2 between packers 3 and 4. The inflow rate will therefore be distributed along this section. Other sections of the perforated casing can be isolated with packers in a similar way.

In those cases where the separator is located in an open, uncased well section, packers may isolate towards the rock surface in the open hole. In some cases a sand screen can be installed to prevent solid particles to follow the incoming flow. The description further on will however only cover the cased alternative since the functional description will be the same.

Since the inflow is distributed over a long section outside the separator, the inflow rate per unit length is low and a pre-separation of the fluids will occur due to gravity. The

lightest fluid, in particular the hydrocarbon fluid, will move upward and collect in the uppermost part of the annulus between the separator chamber and the casing 2 and in the area towards the packer 4. The heavier fraction, i.e. water, will move downwards and collect in the lowermost part of the annulus between the separator chamber and the casing 2 and in the area towards the packer 3.

The separator has a first inlet opening 13 in an upper wall 9 and a second inlet opening 14 in a lower wall 10. The orientation of the inlet openings 13 and 14 in an upper opening 13 and a lower opening 14 is important to take advantage of the pre-separation of the well fluids that take place in the annulus between the casing 2 and the separator. Hydrocarbon enriched fluid will tend to collect in the upper part of the sealed off zone between the packers 3 and 4 and water enriched fluid will tend to collect in the lower part of this zone. Thus the hydrocarbon enriched fluid will enter through the upper inlet opening 13 and the water enriched fluid will enter through the lower inlet opening 14. The separator has a lower end wall 15 and an upper end wall 16, that together with the upper wall 9 and the lower wall 10 enclose the separator chamber 17.

In the embodiment shown in figure 1 is an outlet pipe 7 arranged near the upper wall 9 and the upper end wall 16. The outlet pipe 7 is designed to lead the hydrocarbons out of the separator. In a corresponding way an outlet pipe 8 is arranged near the lower wall 10 and the lower end wall 15. The outlet pipe 8 is designed to lead the water out of the separator. The hydrocarbon outlet pipe 7 is arranged near the upper wall 9 of the separator, to collect the hydrocarbons that accumulates near this wall. The water outlet pipe 8 is arranged near the lower wall 10 of the separator, to collect the water that will accumulate near this wall.

The two outlet pipes 7, 8 are preferably designed to collect the hydrocarbons and water, respectively, along a length of the pipe that is provided with openings 11 and 12, respectively. Preferably, the openings 11 and 12 have decreasing opening areas towards the respective upper end walls 16 and lower end wall 15 so that the hydrocarbons and water, respectively, is drawn out with decreasing amount along the length of the outlet pipes 7, 8 to allow coalescence of the smaller droplets in the areas towards the end walls

16 and 15. Preferably, the outlet pipes are of a design described in detail in Norwegian Patent Application No. 2000 1954 (corresponding to PCT/NO01/00156) of the present applicant, which is incorporated herein by reference.

The separation of the hydrocarbons and water will be governed by gravity and fluid viscous forces. Final coalescence of dispersed oil droplets will take place in the water column above the lower end wall 15. In a similar way the dispersed water droplets will coalesce and settle in the oil column near the upper end wall 16.

The separator may be divided (although not necessarily physically) into three sections

- a lower section 18 comprising the lower end wall 15, the water outlet pipe 8 and the parts of the upper wall 9 and the lower wall 10 that are closest to the lower end wall 15,
- an upper section 19 comprising the upper end wall 16, the hydrocarbon outlet pipe 7 and the parts of the upper wall 9 and the lower wall 10 that are closest to the upper end wall 16,
- and a middle section 20 comprising the inlet openings 13 and 14 and parts of the upper and lower walls 9, 10 that are close to the inlet openings 13, 14.

The separator will now be described in more detail under reference to figures 2a – 2d, 3a – 3d and 4a – 4d.

Figures 2a – 2d show the lower section 18 of the separator. In figure 2a the lower section 18 is shown in the same cross section as in figure 1. This shows the parts of the upper wall 9 and the lower wall 10 closest to the lower end wall 15, containing the water outlet pipe 8. The water outlet pipe 8 is connected to a water flow pipe 21 through a control valve 36 and a transition pipe 22 which set the water outlet pipe 8 in fluid connection with the water flow pipe 21. The water flow pipe 21 extends through the length of the separator as shown in, e.g., figure 1.

Figure 2b shows a cross section along G – G in figure 2a. In this cross section the water flow pipe 21 and the water outlet pipe 8 are shown, as well as a hydrocarbon flow pipe

23, which also extends through the length of the separator parallel to the water flow pipe 21.

As can also be seen from figure 2b, the upper wall 9 and the lower wall 10 together forms a cylinder. The upper wall 9 extends down to the water flow pipe 21 and the hydrocarbon flow pipe 23, and the lower wall 10 extends up to the two pipes 21 and 23. In practice the upper and lower walls 9 and 10 are made integrally from a tubular shape.

Figure 2d shows a cross section along C – C in figure 2a and shows the water flow pipe 21 and the hydrocarbon flow pipe 23 situated in the separator chamber 17.

In figure 2c the lower section 18 of the separator is shown in a longitudinal section transverse to the longitudinal section of figure 2a, along B – B in figure 2d. In this view both the water flow pipe 21 and the hydrocarbon flow pipe 23 are visible. A part of the water outlet pipe 8 and that transition pipe 22 are also visible between the pipes 21 and 23.

As can be seen from figures 2a and 2c, the water flow pipe 21 is connected to a joint chamber 24, which is situated behind the separator end wall 15. The hydrocarbon flow pipe 23 is connected to a bend 25, which passes through the joint chamber 24. The end of the bend 25 furthest from the hydrocarbon flow pipe 23 is centrally situated in the joint chamber 24. The joint chamber 24 and the bend 25 is intended for coupling to a joint chamber 24' and an bend 25' in a second separator situated below the lower section 18.

Referring to figures 3a – d, the upper section 19 will be described. The upper section 19 is similar to the lower section 18, except that it is oriented so that the hydrocarbon outlet pipe 7 is situated near the upper wall 9, while the water outlet pipe is situated near the lower wall 10 in the lower section 18.

In figure 3a the upper section 19 is shown in the same cross section as in figure 1. This shows the parts of the upper wall 9 and the lower wall 10 closes to the upper end wall

16, containing the hydrocarbon outlet pipe 7. The hydrocarbon outlet pipe 7 is connected to the hydrocarbon flow pipe 23 through a control valve 37 and a transition pipe 26 which connects the hydrocarbon outlet pipe 7 to the hydrocarbon flow pipe 23. The hydrocarbon flow pipe 23 extends through the length of the separator as explained earlier.

Figure 3b shows a cross section along F – F in figure 3a. In this cross section the water flow pipe 21, the hydrocarbon flow pipe 23 and the hydrocarbon outlet pipe 7 are shown.

Figure 3d shows a cross section along H – H in figure 2a and shows the water flow pipe 21, the hydrocarbon flow pipe 23 and the hydrocarbon outlet pipe 7, as well as the transition pipe 26, situated in the separator chamber 17.

In figure 3c, the upper section 19 of the separator is shown in a longitudinal section transverse to the longitudinal section of figure 3a, along B – B in figure 3d. In this view both the water flow pipe 21 and the hydrocarbon flow pipe 23 are visible. The hydrocarbon outlet pipe 7, control valve 37 and the transition pipe 26 are also visible, partly covering the pipes 21 and 23.

As can be seen from figures 3a and 3c, the water flow pipe 21 is connected to a joint chamber 27, which is situated behind the separator upper end wall 16. The hydrocarbon flow pipe 23 is connected to a bend 28, which passes through the joint chamber 27. The end of the bend 28 furthest from the upper end wall 16 is centrally situated in the joint chamber 27. The joint chamber 27 and the bend 28 is intended for coupling to a joint chamber 27' and an bend 28' in a second separator situated above the upper section 19 in a similar way as described for joint chamber for the lower section.

Referring to figures 4a – 4d, the middle section 20 will be described.

Figure 4a shows the middle section in the same view as in figure 1. The inlet openings 13 and 14 from the well annulus into the separator chamber 17 are shown. Close to the openings 13 and 14 baffle plates 29, 30, 31 and 32 are placed. These are intended to keep the in-flowing well flow from disturbing the fluids already inside the separator to avoid re-mixing of the already partly separated phases.

Figure 4b shows a cross section along D – D in figure 4a. The openings 13 and 14, the baffle plates 30 and 32, and the water and hydrocarbon flow pipes 21 and 23 are shown.

Figure 4d shows a cross section along E – E in figure 4a. Also here the baffle plates 30 and 32, and the water and hydrocarbon flow pipes 21 and 23 are shown.

Figure 4c shows a longitudinally section along B – B in figure 4d. The water flow and hydrocarbon flow pipes 21 and 23 are shown. Also shown are the opening 14 and the baffle plates 31 and 32. As can be seen from figure 4c the baffle plates 31 and 32 are in fact one plate, in which an opening is formed, which is coincident with the opening 14. The inlet arrangement is very simple. In tests it proved very important to include the baffle plates to protect the counter current separated flow from the incoming fluid flow. The inlet flow openings 13 and 14 can however have different shape than shown and even consist of several separate openings in the same area.

As shown in figure 4a, a first level gauge 33 is placed below the inlet openings 13, 14 to measure the top level of the water phase, and a second level gauge 34 is placed above the inlet openings 13 and 14 to measure the bottom level of the hydrocarbon phase. If the top level of the water phase rises above the first level gauge 33 the outtake of water through the water outlet pipe 8 (shown in figure 1) will have to be increased and/or the outtake of hydrocarbons through the hydrocarbon outlet pipe 7 (shown in figure 1) will have to be decreased. If on the other hand the bottom level of the hydrocarbon phase sinks below the second level gauge 34, the outtake of hydrocarbons through the hydrocarbon outlet pipe will have to be increased and/or the outtake of water through the water outlet pipe will have to be decreased.

Control the outflow rate is preferably performed by the adjustable valves 36, 37 at the two outlets based on measurement of the oil/water interface level within the mid-section of the separator chamber. Balancing of the flow rate sharing between each separator is preferably done by tuning the outlet flow from each separator to handle a pre-determined portion of the overall inflow rate.

The joint between two separators according to the present invention will now be described referring to figures 5a and 5b.

As can be seen from figure 5a, which in reality shows the same as the left end of figure 2c the water flow pipe 21 of the right hand separator and the water flow pipe 21' of the left hand separator are connected to a respective joint chamber 24 and 24'. The joint chambers have the same inner and outer diameter as the separators and are in fact an integrated part of the respective separator walls 9, 10. The two joint chambers 24 and 24' are joined together by an outer sleeve 35 having right and links threads engaging with similar threads outside the walls 9, 10, 9', 10'. The joint chambers 24 and 24' are thereby being pulled together turning sleeve 35. A key-arrangement (not shown) will ensure that the two separator units are being rotationally correctly oriented when mated together. The hydrocarbon flow pipes 23 of the right hand separator and the hydrocarbon flow pipe 23' of the left hand separator are connected to respective bends 25 and 25'. The facing ends of the bends 25 and 25' are centrally situated in the joint chamber 24, 24', as shown in the cross section of figure 5b along C – C. The bend 25 extends a little distance into the joint chamber 24', so that the bends 25 and 25' overlaps. The bend 25 has also a larger diameter than the bend 25', so that the bends 25 and 25' mate in a sealed co-centric male/female coupling.

Any number of separators according to the present invention can be joined together as shown. Thus the separators can separate well fluids from different zones in the well. The water flow pipes and the hydrocarbon flow pipes will extend continuously through the interconnected separators, which will contribute to the flow of the phases by adding fluids through the transition pipes 22 and 26 respectively. This way any number of

separators can physically be interconnected one after the other, but operatively they are coupled in parallel.

The separator housing is a closed chamber. The inlets are at top and bottom along a vertical line. This orientation provides for pre-separated hydrocarbons to enter the separation chamber though the upper inlet opening 13 and the pre-separated water to enter the separator chamber through the lower inlet opening 14. The separator must be installed with an orientation means to make sure that the hydrocarbon inlet at the top and the water inlet at bottom.

For a separator according to the invention to be used in a horizontal part of the well, the inlet openings could be situated at one end of the separator and the outlet openings at the opposite end of the separator. The arrangement would imply a co-current flow of the phases as opposed to a counter-current flow.

To make the separator practical for installation and ensure easy drill-floor handling, the following design features are preferably included:

- Make each separator cell (CS cell) to a standardized size and construction (so that overall capacity will be the sum of units).
- Design to fit standard and most common casing diameter sizes
- Maximum length to be kept within maximum practical handling dimensions (12 - 14 m)
- Type of couplings to be used to ensure CS cells to be connected with the same rotational orientation, preferably: union couplings at each separator section, rotational orientation of each section with a key-arrangement.
- Means of orienting the unit in the bore hole to make the oil inlet appear on top and water inlet at bottom, preferably: packer with key and CS cell with orienting slot.
- Robust and simple design per common drilling equipment standards.
- Single wire data transfer system for monitoring and control. Daisy-chain connection of valves and sensors by jumper cables from each unit to the next.

Claims

1.

Device for downhole counter-current separation of well fluids, characterised in that it comprises:

- a separator housing having walls (9, 10, 15, 16) defining a separator chamber (17) thereinbetween and also defining an annulus between the walls and a casing (2) in the well bore;
- a water outlet (8) and a hydrocarbon outlet (7) from said separator chamber (17); and
- a well flow inlet (13, 14) to the chamber (17), communicating with the annulus.

2.

Device for downhole separation of well fluids, comprising:

- a separator housing having walls (9, 10, 15, 16) defining a separator chamber (17) thereinbetween;
- a water outlet (8) and a hydrocarbon outlet (7) from said separator chamber (17);
- a well flow inlet (13, 14) to the chamber (17), communicating with the well bore, optionally an annulus between the separator housing and a casing (2) in the well bore,
- characterised in that the well flow inlet comprises an upper well flow inlet (13) and a lower well flow inlet (14), said upper well flow inlet (13) being situated at a higher level than said lower well flow inlet (14).

3.

Separator device for downhole separation of well fluids, characterised in that the device comprises:

- at least two separator cells, each separator cell comprising a separator housing, said separator housing having walls (9, 10, 15, 16) defining a separator chamber (17) thereinbetween;
- a water outlet (8) and a hydrocarbon outlet (7) from said separator chamber (17);
- a well flow inlet (13, 14) to the chamber (17);
- a water flow channel (21) communicating with said water outlets (8) of said at least two separator cells; and
- a hydrocarbon flow channel (23) communicating with said hydrocarbon outlets (7), to provide a parallel operation of said separator cells.

4.

Device according to claim 3, c h a r a c t e r i s e d i n that said separator cells are coupled physically end to end.

5.

Device according to claim 4, c h a r a c t e r i s e d i n that said water flow channel (21) and said hydrocarbon flow channel (23) are situated within said walls (9, 10, 15, 16).

6.

Device according to any of the claims 3 - 5, c h a r a c t e r i s e d i n the water flow channel (21) and the hydrocarbon channel (23) are in communication with the water outlets (8) and the hydrocarbon outlets (7), respectively, through a respective control valve (36, 37).

7.

Device according to one of the claims 3 - 6 , c h a r a c t e r i s e d i n that the separators are counter-current separators.

8.

Device according to one of the claims 3 – 7, c h a r a c t e r i s e d i n that the separator device is placed in a well bore which is divided into at least two zones by sealing off said zones with packers (3, 4), said at least two zones communicating well fluid into a different separator cell or a different set of separators cells.

9.

Device according to any of the preceding claims, c h a r a c t e r i s e d i n that the well flow inlet (13, 14) is situated at a substantial distance from said water outlet (8) and said hydrocarbon outlet (7).

10.

Device according to any of the preceding claims, c h a r a c t e r i s e d i n that the separator is situated in an inclined part of the well bore, that walls of the separator housing comprises a lower end wall (15) and an upper end wall (16), and an upper wall (9) and a lower wall (10), said upper wall (9) and said lower wall (10) extending between said lower end wall (15) and said upper end wall (16), the water outlet (8) being situated near said lower wall (10), and the hydrocarbon outlet (7) being situated near said upper wall (9).

11.

Device according to claim 10, c h a r a c t e r i s e d i n that the water outlet (8) being situated near said lower end wall (15) (in the end facing downwards of the separator chamber 17), and the hydrocarbon outlet (7) being situated near said upper end wall (16)) (in the end facing upwards of the separator chamber (17).

12.

Device according to any of the claims 10 – 11, c h a r a c t e r i s e d i n that an upper well flow inlet (13) is formed in the upper wall (9) and a lower well flow inlet (14) is formed in said lower wall (10).

13.

Device according to any of the preceding claims, c h a r a c t e r i s e d i n that the well flow inlet comprises baffle plates (29, 30, 31,32), to prevent the flow of well fluid entering the separator chamber (17) from disturbing the fluids already inside of the separator chamber (17).

14.

Device according to any of the preceding claims, c h a r a c t e r i s e d i n that it further comprises at least one level gauge (33, 34) near said well flow inlet (13, 14), optionally, a first level gauge (33) on a first side of said well flow inlet (13, 14) and a second level gauge (34) on a second side of said well flow inlet (13, 14), said second side being at a higher altitude than the first side.

15.

Device according to any of the preceding claims, c h a r a c t e r i s e d i n the separator housing being provided with a first packer (3) situated on a first side of said well flow inlet (13, 14) and a second packer (4) situated on a second side of said well flow inlet (13, 14), said packers (3, 4) sealing off a zone of the annulus at the vicinity of the separator housing, said zone communicating with the separator chamber (17) through said well flow inlet (13, 14).

16.

Device according to any of the preceding claims, c h a r a c t e r i s e d i n that the water outlet (8) and the hydrocarbon outlet (7) comprise a series of outlet openings (11, 12) distributed along a length of the separator chamber (17) and sized to receive a decreasing amount per unit length towards the downstream end.

17.

Device according to any of the preceding claims, c h a r a c t e r i s e d i n a water flow channel (21) and a hydrocarbon channel (23) extending through said separator chamber (17), said water outlet (8) being in communication with said water flow

channel (21) and said hydrocarbon outlet (7) being in communication with said hydrocarbon channel (23).

18.

Device according to claim 17, c h a r a c t e r i s e d i n that said water flow channel (21) is a tube.

19.

Device according to claim 17, c h a r a c t e r i s e d i n that said hydrocarbon flow channel (23) is a tube.

20.

Device according to one of the claims 17 – 19, c h a r a c t e r i s e d i n that said water flow channel (21) and said hydrocarbon channel (23), at least at one of their ends, are terminated in a joint section, said joint section being adapted for coupling to a joint section of a further separator device.

21.

Device according to claim 20, c h a r a c t e r i s e d i n that said joint section comprises a joint chamber (24, 24'), one of said water flow channel (21) or said hydrocarbon channel (23) being in communication with said joint chamber (24, 24'); and a pipe section (25, 25'), the other of said water flow channel (21) or said hydrocarbon channel (23) being in communication with said pipe section (25, 25').

22.

Method for downhole separation of well fluids, c h a r a c t e r i s e d i n that hydrocarbon producing zones in a well bore are sealed off, well fluid is drawn out of a respective formation adjacent the zones, well fluid entering the respective zones is separated into water and hydrocarbons in downhole separators, the separation of the well fluid from the respective zones taking place independent of one another.

23.

Method according to claim 22, c h a r a c t e r i s e d i n that the respective separators are placed in the respective zones and isolated from each other by packers.

24.

Method for downhole separation of well fluids, c h a r a c t e r i s e d i n that a separator is placed in a hydrocarbon producing zone in a well, said zone is sealed off and set in communication with the separator through an upper well flow inlet (13) and a lower well flow inlet (14), said upper well flow inlet (13) being situated at a higher level than said lower well flow inlet (14).

25.

Method according to claim 24, c h a r a c t e r i s e d i n that separators are placed in a multiple of zones, said zones are sealed off from each other and said respective zones are communicating with a respective of said separators.

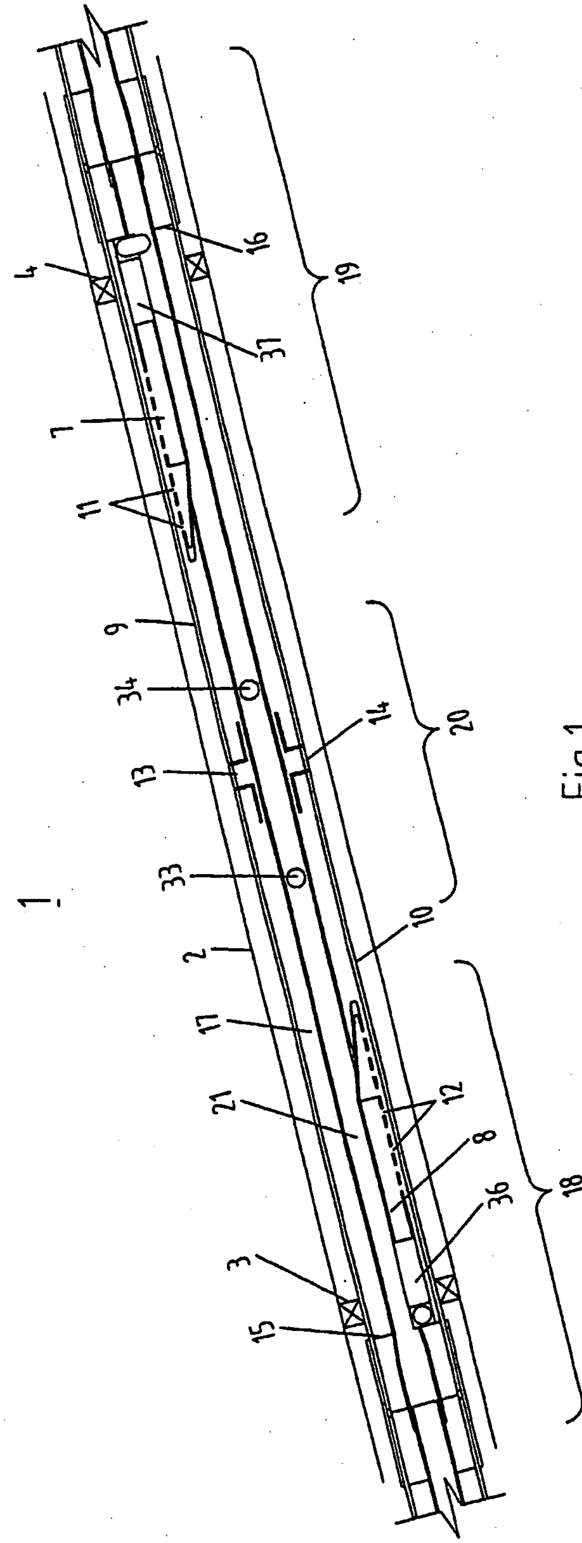
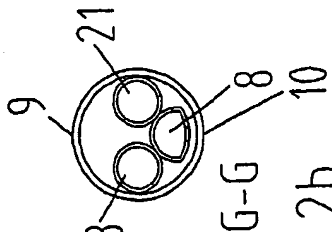
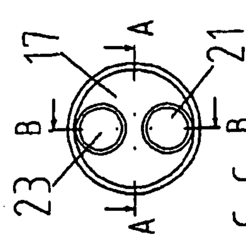


Fig.1



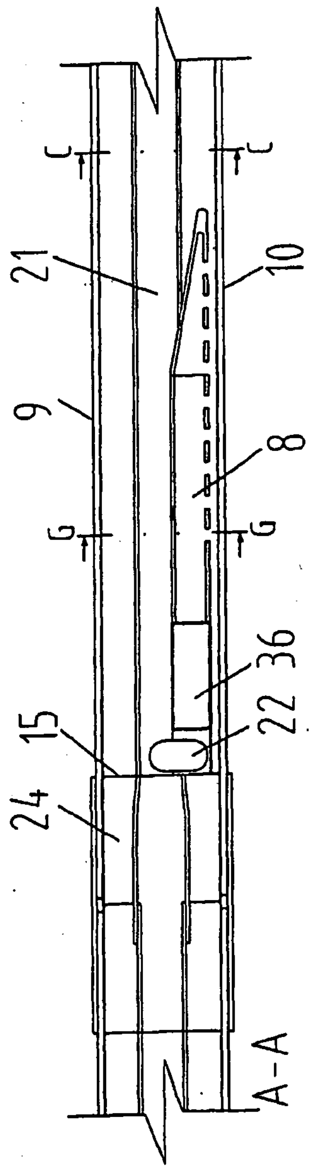
G-G

Fig.2b



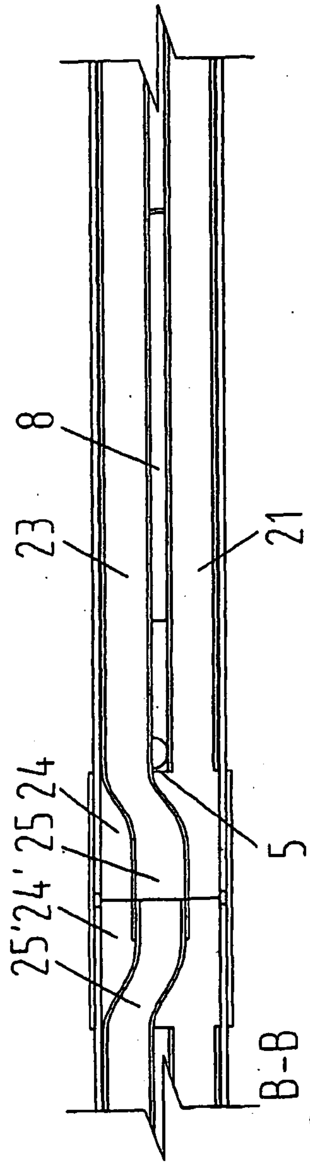
C-C

Fig.2d



A-A

Fig.2a



B-B

Fig.2c

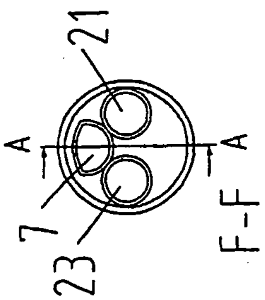


Fig.3b

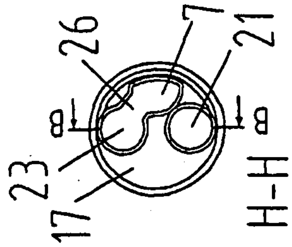


Fig.3d

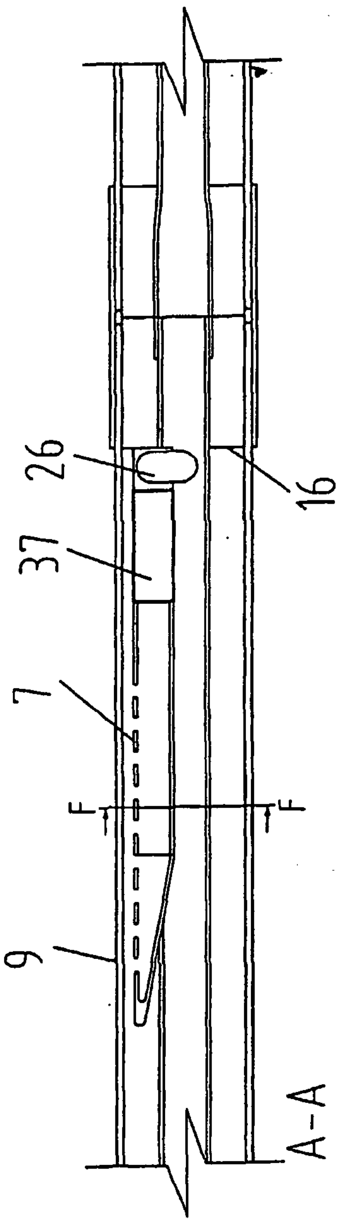


Fig.3a

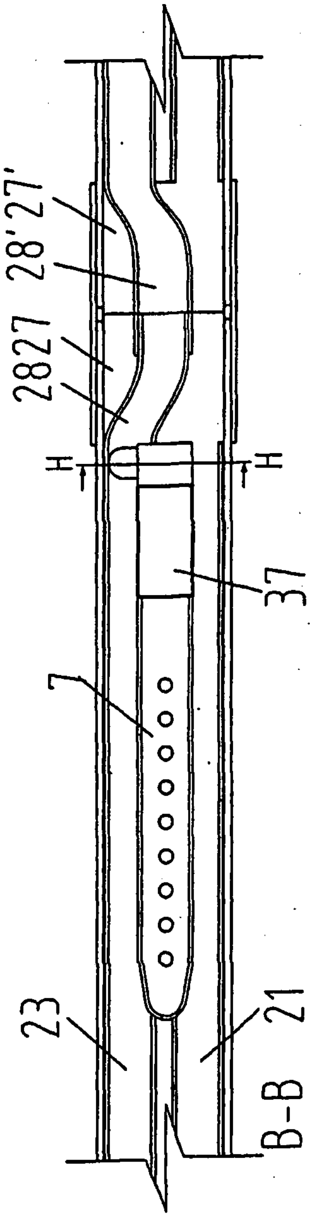


Fig.3c

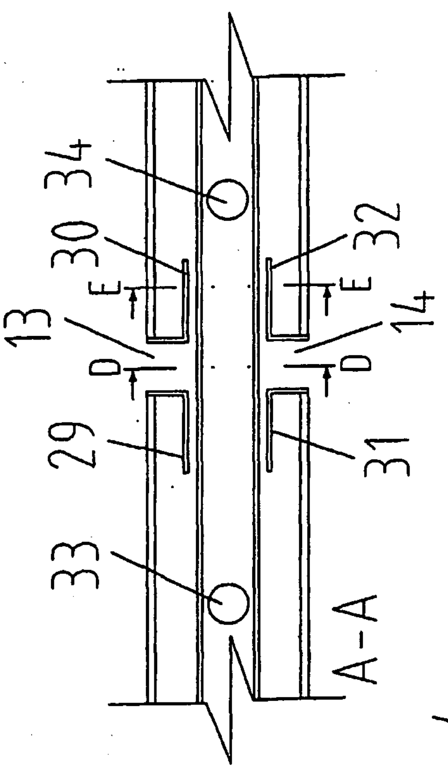


Fig.4a

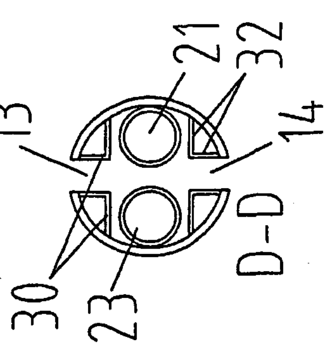


Fig.4b

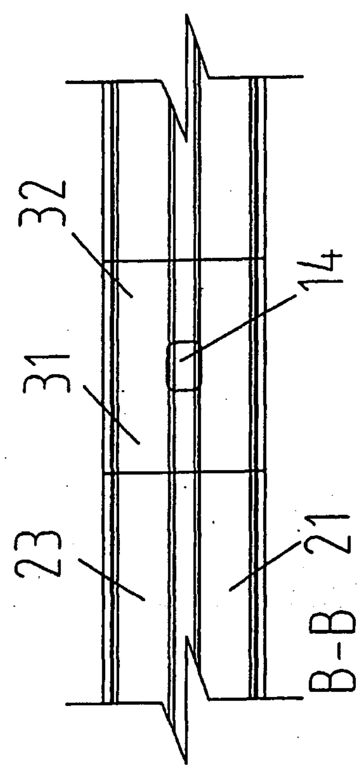


Fig.4c

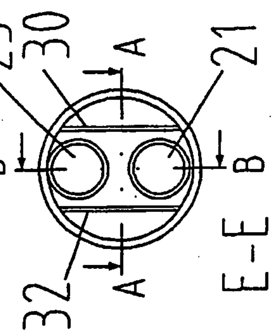


Fig.4d

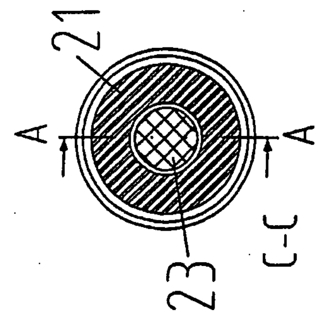


Fig.5b

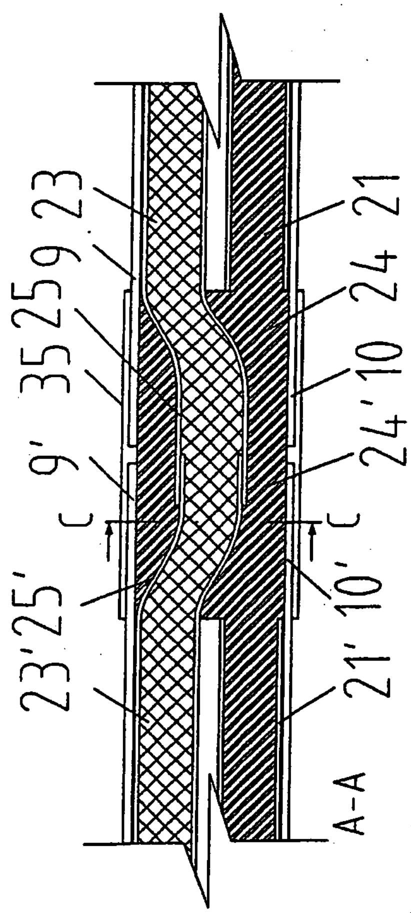


Fig.5a

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 03/00018

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: E21B 43/38, B01D 17/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: E21B, B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5443120 A (D.A. HOWELL), 22 August 1995 (22.08.95), the whole document	1,3-11,15, 22-23
Y		13
	--	
Y	WO 9958455 A1 (HYDROMATION FILTER COMPANY, INC.), 18 November 1999 (18.11.99), the whole document	13
	--	
A	US 2001017207 A1 (S.A. HAHEIM), 30 August 2001 (30.08.01), the whole document	1,3-9,15, 22-23
	--	
A	WO 0201044 A1 (DEN NORSKE STATS OLJESELSKAP A.S), 3 January 2002 (03.01.02)	1-25
	--	

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 April 2003	23-04-2003
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Christer Bäcknert / MRo Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

29/03/03

International application No.
PCT/NO 03/00018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5443120 A	22/08/95	CA 2155704 A	26/02/96
		GB 2292574 A,B	28/02/96
		GB 9516271 D	00/00/00
		NO 309016 B	27/11/00
		NO 953282 A	26/02/96
WO 9958455 A1	18/11/99	EP 0994824 A	26/04/00
		US 5989415 A	23/11/99
		US 6200490 B	13/03/01
US 2001017207 A1	30/08/01	GB 0104435 D	00/00/00
		GB 2359575 A	29/08/01
		NO 311814 B	28/01/02
		NO 20000900 A	24/08/01
WO 0201044 A1	03/01/02	AU 6443601 A	08/01/02
		NO 20003291 D	00/00/00
		NO 20025892 A	09/12/02